

# Methods for assessing the contribution of renewable technologies to energy security: the electricity sector of Fiji

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In recent years, renewable energy technologies have been advocated in Fiji on the basis that they improve energy security and serve as a risk-mitigation measure against oil price volatility. Despite this, there have been no published attempts to measure the impact of renewable technologies on energy security or to assess the major threats to that security. This analysis is important if the benefits of renewable energy sources in Fiji are to be evaluated adequately. This article considers the key threats to the security of electricity supply in Fiji for grid-connected and off-grid areas and uses these as a basis for a definition of energy security that is relevant to Fiji. It proposes a method for assessing the potential contribution of renewable technologies to the security of electricity supply in Fiji, based on mean-variance portfolio theory used in financial markets.

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In recent years, renewable energy technologies have been advocated in Fiji on the basis that they improve energy security and serve as a risk-mitigation measure against oil price volatility and high oil prices. These arguments in favour of renewable energy technologies (renewables), grounded in economic and security language, differ from those of the past, advocating renewables for rural electrification on primarily environmental and social grounds.

This change in emphasis is the result of significant oil price volatility in recent years and especially the 2008 oil price spike which adversely affected the economies and energy security of Pacific island countries. As a result, energy security issues are once again on the agenda in the region, with the energy security benefits of renewable technologies often referred to in these discussions. Despite this, there have been few attempts to quantify the impact of different technologies on energy security in the



electricity sector. Furthermore, there has been little analysis of how risk-mitigation influences electricity sector investment decisions in the electricity grid and in rural areas where electricity is provided using off-grid generation technologies.

This article outlines two methods for assessing the potential contribution of renewable technologies to the security of electricity supply in the grid and in off-grid rural areas of Fiji. The method proposed for the grid closely resembles the mean-variance portfolio approach used to measure risk in financial markets. In rural areas where off-grid generation supplies electricity, an alternative approach is used in order to better consider risks specific to rural Fiji.

## Oil price volatility and renewable technologies

The economies of Pacific island countries have been adversely affected in recent years by high oil prices, culminating in the record oil prices of 2008 (Figure 1). The effects of these prices on Pacific economies have been documented elsewhere and include fiscal and current account blowouts (ADB 2008; Levantis 2008a, 2008b; Levantis, Groeger and McNamara 2006; Tumbarello 2008; UNDP 2007b). In Fiji, for example, the value of oil imports rose from approximately 5 per cent to 12 per cent of GDP between 2002 and 2008. This meant effectively a negative impact on gross national income

Figure 1 **Oil price, January 2002 – June 2009** (weekly all-countries spot price FOB weighted by estimated export volume)



Source: Energy Information Administration, 2009, <http://tonto.eia.doe.gov/>



of 7 per cent and is one reason (although certainly not the only one) for Fiji's lacklustre economic performance in recent years. In several Pacific island countries, high oil prices have also led to crises in the electricity sector, which are generally state owned and are often subsidised. Electricity was rationed in several cases as a result. In the extreme case of the Marshall Islands, the government declared an economic 'state of emergency' in July 2008 when it appeared that electricity generation would cease as a result of the government-owned utility's inability to pay for the diesel fuel required to operate generators (Taiwan stepped in with funding support at the last moment) ('Marshall Islands declares state of economic emergency', *Islands Business*, 4 July 2008).

There are two main reasons why oil price volatility had such an impact on Pacific island countries. First, Pacific island economies are very energy intensive, meaning that they use a large amount of energy for every dollar of income that is generated. This is largely a result of their reliance on long-distance transportation and the importance of various energy-intensive activities such as fishing (Levantis 2008a, 2008b). The second reason is that Pacific island economies (excluding Papua New Guinea) are reliant mainly on fossil fuels for their modern energy needs (Tumbarello 2008; Wade 2005). All fossil fuels are imported in the Pacific islands. These fuels are generally sold to Pacific island countries at above world market prices, further accentuating their vulnerability to high oil prices (ADB 2008; Levantis, Groeger and McNamara 2006; Morris 2006; Sanghi and Bartmanovich 2007). Diesel generation also provides the bulk of electricity in most Pacific island countries. Although diesel-based generation is expensive by international standards, cheaper options used in larger countries—such as coal or gas-fired generation—are not feasible in the Pacific islands due to

the relatively small size of electricity grids. The diesel used to produce electricity can make up a significant portion of total diesel imports in Pacific island countries. In Fiji, for example, about 26 per cent of imported fuel is used to generate electricity (Johnston, Wade, Sauturaga, Vega and Vos 2005), amounting to more than 3 per cent of GDP. This figure is likely to be higher for other Pacific island countries, as most generate a lower proportion of their electricity using renewable technologies and many are likely to use less fuel for transport than Fiji.

Fiji is different to other countries in the region, as a substantial proportion of its modern energy needs are met from renewable energy sources. In particular, hydropower has played an important role in Fiji's electricity sector since the commissioning of the Monasavu hydro scheme in 1983 (FEA 2007, 2008a). The scheme initially provided 100 per cent of the electricity requirements of Viti Levu (the main island of Fiji) but, with time, demand has increased and the contribution of hydropower to total generation has decreased. There has been a steady decline in the share, although not amount, of hydro-based electricity generation for the Fiji Electricity Authority (FEA), which produces more than 95 per cent of Fiji's electricity (Figure 2). In this same period, thermal generation—including diesel and heavy fuel oil—is shown to have increased. There is, of course, variation in these figures from year to year—mainly as a result of annual variations in rainfall. The last two years showed increased amounts of electricity generated from hydro, largely as a result of good rainfall in the Monasavu catchment. Indeed, in 2007, hydro-based generation reached its highest level since the commissioning of the Monasavu scheme.

The vulnerability of Pacific economies to oil price volatility and the significant movements in world oil prices in the past decade

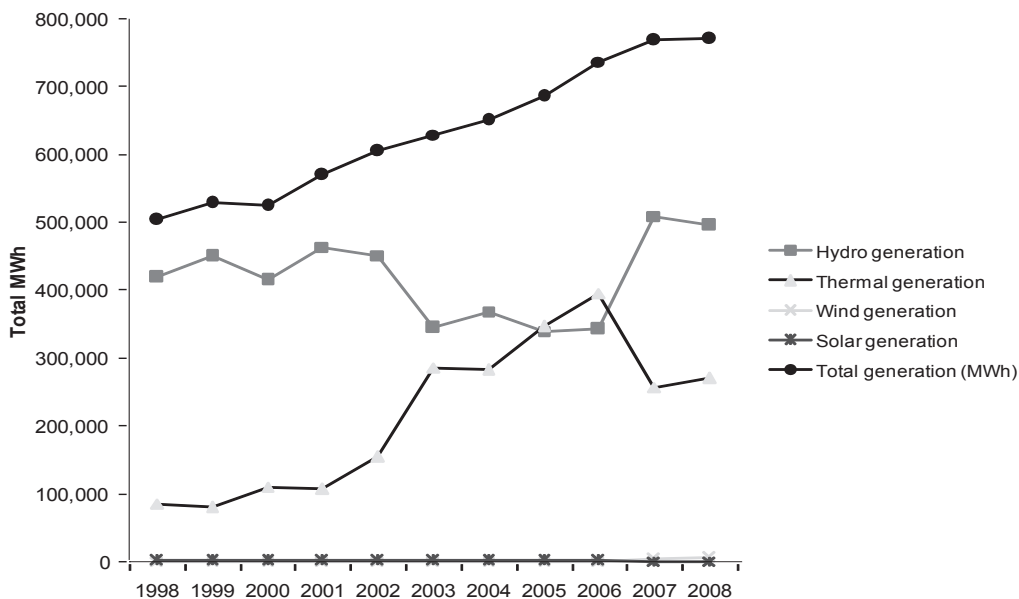


have placed energy security issues firmly on the agenda in many Pacific island countries. Advocates of renewable energy technologies emphasise the contribution that renewables could make to energy security by reducing the amount of oil that must be purchased for electricity generation. This impacts on energy security in the grid and in rural areas where off-grid generation supplies power by reducing the exposure of utilities and/or communities to oil price volatility. The fact that renewable technologies address both energy security and climate change objectives no doubt adds to their appeal. Energy security arguments have been used in Fiji in support of recent renewable energy investments. For example, the FEA (2008b) has stated that its goal in implementing

renewable energy projects is to reduce its fuel importation bill and lessen its exposure to oil price volatility. Such projects are also consistent with the FEA's aim to generate 90 per cent of its electricity using renewable energy technologies by 2011 (FEA 2007, 2008a).

Despite references to the energy security implications of renewable energy technologies, there is, however, seldom any analysis of what exactly is meant by the term 'energy security', or what the primary threats to energy security are in Pacific island countries. Furthermore, there has been little analysis of the extent to which renewables can improve energy security in the electricity sector (beyond calculations of reductions in diesel consumption resulting

Figure 2 FEA electricity generation by technology



Sources: Fiji Electricity Authority (FEA), 2007. *Annual Report*, Fiji Electricity Authority, Suva; Fiji Electricity Authority (FEA), 2008a. *Annual Report*, Fiji Electricity Authority, Suva.



from renewable technologies). These are significant gaps in knowledge. To evaluate the benefits of renewable technologies adequately, their contribution to energy security needs to be examined properly. To do this, a clear definition of energy security and an understanding of the main threats to energy security in Fiji are needed. It is to these questions that this article now turns.

## Energy security in Fiji

### What is energy security?

Bohi and Toman (1996) argue that 'energy security refers to the loss of economic welfare that may occur as a result of a change in the price or availability of energy'. This definition can be broadened to include cases where the costs of energy supply are consistently high in the long run. The welfare losses resulting from cuts in energy supply are generally considered substantial. Most forms of modern economic activity depend on secure and affordable supplies of 'modern energy', which refers to electricity and fossil fuels but not 'traditional' forms of energy such as biomass (WBCSD 2007). Because of its role in fueling economic activity, modern energy can be understood as a prerequisite (although alone, not a sufficient condition) for economic growth, sustainable development and even poverty alleviation (IAEA 2005; UNDESA 2005; Johansson and Goldemberg 2004; UNDP 2007a; <http://www.forumsec.org.fj/pages.cfm/economic-growth/energy/>). The importance of modern forms of energy is affirmed by the Pacific Islands Forum Secretariat (n.d.), which states that '[e]nergy has a vital role in achieving economic growth and sustainable development in the Pacific region. It is a fundamental input to most economic and social activities and a prerequisite for development in other sectors such as education, health and communications.'

Although energy security is widely recognised as important, there is significant ambiguity surrounding the term (ESCAP 2008). A distinction should first be drawn between short-term risks to energy availability associated with natural disasters or technical problems and long-term risks to energy supply where disruptions continue for weeks or months (IEA 2007). The focus of this article is on the latter—as is most economic and security research. Long-term *physical* supply disruptions have traditionally been the main centre of attention of the energy security literature. A growing number of authors, however, argue that the term has been redefined by the extensive international markets that exist for energy, and that it should be focused more on the price of oil and its implications for affordability (Helm 2002; Ocheltree n.d.; Toman 1991, 2002). Michael Toman (1991) pursues this argument, stating that 'significant shortages never will be seen in a well-functioning market, but price increases signalling increased resource scarcity can be. These price changes should be the focus of policy.' In other words, in areas where markets are developed, any scarcity of energy will impact on consumers through the price mechanism. In such situations, energy prices will rise and/or will be highly volatile; however, there will not be supply shortages as such. Of course, energy security can still be threatened. According to the definition of energy security provided above, the economic welfare of consumers will be affected negatively by rises in the price of energy and by corresponding reductions in energy consumption. Often those people reducing consumption will be low-income consumers for whom price increases are unaffordable. Energy insecurity as experienced through the price mechanism therefore also involves an equity dimension.



The key assumption in this understanding of energy security is that markets exist and are well functioning. This might be a fair assumption in parts of Europe or the United States. It is, however, often not the case in Pacific island countries—especially in rural areas where subsistence livelihoods are common. Indeed, even in the electricity grid of many Pacific island countries, electricity prices that are set by the government can be inflexible to cost changes, changes in availability and changes in demand. In some Pacific nations, this inflexibility has recently resulted in supply disruptions as oil price increases raise generation costs that have not been matched by an increase in electricity tariffs. In fact, in many Pacific island countries, electricity tariffs are consistently below the cost of providing electricity and governments must subsidise the state-owned electricity utility. Increases in generation costs that are not met by tariff increases can in these cases threaten fiscal balance.

The extent to which threats to energy security are physical or price-based is therefore dependent on the structure and presence of markets for energy. As a result, energy security risks for the electricity grid can be expected to differ markedly from those in rural areas, where off-grid and mini-grid systems supply electricity and markets are not as well developed. A comprehensive examination of energy security in Fiji will therefore need to identify and determine the importance of physical and price aspects of energy security. This is consistent with the approach pursued by the International Energy Agency (IEA 2007:12), which argues that '[e]nergy insecurity stems from the welfare impact of either the physical unavailability of energy, or prices that are not competitive or overly volatile...the relative importance of these depends on the market structure, and in particular the extent to which prices are set competitively or not'.

Considering physical supply and the price aspects of energy security is also consistent with the methods proposed in this article for analysing the security of electricity supply in Fiji. The relative importance of each aspect differs for areas of Fiji where electricity is supplied through the grid or through off-grid generation, meaning that different measures of security of supply must be used. Below, the key threats to security of electricity supply are considered separately for each of these areas. This discussion provides the basis for the next section, in which methods to measure energy security in the electricity sector are proposed.

### **Threats to energy security in Fiji's electricity sector**

The FEA is a state-owned electricity utility that provides electricity to grid-connected areas of Fiji. Two sets of markets are particularly important for the energy security of FEA-supplied electricity: factor markets for fuel and product markets where electricity is sold. Aside from hydropower, the main fuels used to generate electricity by the FEA are diesel and heavy fuel oil—both sourced from international markets. These markets are generally considered to be developed and competitive—regardless of monopoly power among larger oil companies and Organization of Petroleum Exporting Countries (OPEC) members. Accordingly, when fuel is scarce, its price should rise, prompting supply from 'marginal' sources of fuel and reducing demand, thereby ensuring that supply shortages do not occur. When the price of fuel rises, the FEA's generation costs also rise. The manner in which cost increases threaten the security of electricity supply then depends on whether electricity tariffs reflect generation costs.

It is noted above that in many Pacific nations electricity tariffs are lower than generation costs. This has not been the case





in Fiji in recent years, where low generating costs from the Monasavu hydro scheme have allowed the Fijian government to keep electricity tariffs low by Pacific island standards, with only minimal assistance to the FEA (World Bank 2006). Higher demand for power in Fiji is, however, now resulting in financial pressure on the FEA, with increased levels of diesel-based electricity generation and investments in new generating equipment raising costs (Maunsell Limited 2005). Higher electricity tariffs will be needed to meet those costs if the FEA is not to require government subsidies. There seems to be recognition of this within the government, as detailed in the National Energy Policy (Department of Energy 2006). The Commerce Commission, which is responsible for determining tariffs (subject to cabinet approval), is also instructed to consider the FEA's costs in its determinations. Indeed, the Commerce Commission (2009) increased tariffs only recently. The threat posed by oil price volatility to the security of electricity supply in such a situation (where electricity tariffs reflect generation costs) is price based.<sup>1</sup>

There are other threats to energy security that can affect the price of electricity, including changes in operation and maintenance costs and in capital costs. Of these, changes in capital costs are the most significant. These changes can result from unexpected cost blowouts for new projects and/or from currency movements. The FEA has been affected in the past by currency movements. The 30 per cent devaluation of the Fijian dollar after the 1987 coup effectively increased the debt the FEA owed as a result of the Monasavu hydro scheme (which cost about F\$300 million) by approximately F\$99 million, because the debt was denominated in foreign currency (Chaudhari 1995). Such risks can be hedged through financial instruments or by denominating debt in Fijian dollars; however, this is not costless

(the FEA subsequently brought the debt onshore and converted it to long-term bonds that were protected from currency fluctuations). Currency movements can also increase project costs—as has occurred with the Nadarivatu hydro scheme, which is currently under construction.

As argued above, the physical component of long-term energy security in grid-connected Fiji is less important than the price component. Technical issues nevertheless need to be considered in electricity planning and should be included in methods to assess the energy security implications of generation technologies. Of greatest consequence are potential electricity supply shortages related to the high concentration of renewables in the electricity grid. In Fiji, this risk currently applies only to hydropower, which can be affected by drought. Fiji experienced a drought in October 2008 that led to a sharp jump in diesel generation (FEA 2008a; 'FEA prays for rain, power shedding possible', *Islands Business*, 31 October 2008). It is proposed below that such risks be incorporated in the analysis of energy security by setting a maximum proportion of a renewable technology allowed in the grid without backup capacity. An assessment of the maximum amount of hydropower that can be allowed in the Fijian grid on security-of-supply grounds should be the subject of separate assessment based on technical, meteorological and scientific data (more detail on these issues is provided below).

Other physical supply risks are less important and are not included in the proposed method. For example, there is some risk of short-term supply cuts as a result of natural disasters or technical problems; however, these do not impact on the long-term security of supply. There is a very low risk of long-term technical problems in the Fijian electricity grid. This risk is, however, mitigated by ensuring that people with the appropriate expertise are employed to



prevent and/or address technical problems (as occurs at the FEA). The primary threats to the security of electricity supply in grid-connected and off-grid areas of Fiji are shown (Table 1), based on a preliminary assessment of the literature and the author's analysis.

The situation in areas of Fiji where there is no electricity grid is very different to grid-connected areas (Table 1). Threats to the physical availability of electricity in these rural areas are significant, due to the fact that markets for energy in these areas (and indeed markets more generally) are not well developed. The primary threats to security of electricity supply in off-grid areas are therefore related to price and physical supply. The price of diesel fuel is certainly a cause of energy insecurity in rural communities reliant on diesel generators for their electricity, as these communities are often cash poor compared with urban communities. Other

threats to the security of electricity supply exist, including (long-term) technical problems that require distant outside expertise in order to be fixed and the unavailability of diesel fuel due to irregular shipping services (Bygrave 1998; Jafar 2000; Liebenthal, Mathur and Wade 1994; Wade 2005; Woodruff 2007). Many of these physical threats to the supply of off-grid electricity have their basis in the failure of institutional structures created to maintain and operate off-grid and mini-grid electricity systems (Bygrave 1998; Johnston, Wade, Sauturaga, Vega and Vos 2005; Liebenthal, Mathur and Wade 1994; Wade 2005).<sup>2</sup> These institutions are necessary in the absence of strong market incentives for the maintenance and operation of electricity-generation infrastructure. Although the establishment of such institutions has been successful in some cases, in many cases they have not (Bygrave 1998; Retnanestri 2007; Wade 2005).

**Table 1 Indicative significance of threats to security of electricity supply in Fiji**

Component of energy security	Threat to energy security	Fijian electricity grid	Off-grid electricity generation in Fiji
Price	Fuel cost	High for diesel	High—where generation is diesel based
	Operation and maintenance costs	Minor	Medium—depending on fee-collecting institutions
	Capital costs (for example, infrastructure costs)	Medium	Minor
Physical availability	Fuel availability	Medium—high for hydro; low for diesel	High—where generation is diesel based
	Technical problems	Minor—for long-term energy security	High
	Natural disasters	Medium—mainly short-term threat	Medium

**Sources:** Preliminary assessment of the literature and author's analysis.





## Proposed methods for assessing energy security in Fiji

This section proposes the use of two methods to assess the energy security implications of different technologies on electricity supply in Fiji. The first method is appropriate for Fiji's electricity grid and closely resembles the mean-variance portfolio approach traditionally used to assess risk in financial markets. Its focus is on the price component of energy security, which, as argued above, is the most significant threat to the long-term security of grid-supplied electricity. The second method incorporates price and physical supply components of energy security—both of which are important in rural areas of Fiji where electricity is supplied using off-grid and mini-grid systems. Although these methods are proposed for grid-connected and off-grid areas of Fiji, it is likely that they could be adapted for use in other Pacific island countries (and indeed other small island developing states), many of which face similar energy security challenges in the electricity sector. Once again, the determining factor when choosing which of the two methods to use is the extent to which markets ensure that the consumer experiences shortages across the entire economy as higher prices and not cuts in supply.

### Mean-variance portfolio theory

It has already been argued that the key threats to energy security in the electricity grid in Fiji are high prices and price volatility—the long-run determinants of which are changes in generating costs.<sup>3</sup> It follows that the impact of renewable technologies on total generating costs should be the primary focus when assessing their contribution to energy security in the electricity grid. Mean-variance portfolio theory (MVP) provides a method for assessing this impact. MVP

was developed by Harry Markowitz (1952) as a method of valuing financial market securities based on the return and risk implications of each security for a portfolio of financial securities. The value of any security or investment under MVP has two components: its expected (mean) return and the risk associated with that return (being the risk that the real return from the security will differ from its expected return). The risk of a security is defined as the standard deviation of past returns (Awerbuch and Berger 2003; Copeland, Weston and Shastri 2005). Higher returns are generally associated with a higher level of risk.

MVP also considers the return and risk implications of a security in terms of its impact on the return and risk of an investor's *portfolio* of securities. In order to do this, the historical returns of that security must be correlated with those of the portfolio and their correlation coefficient estimated. Where the returns of the security in question are highly correlated with those of the portfolio, it will increase the risk of the portfolio. This is because at a time when the returns of the portfolio are low, the security in question is also likely to provide low returns. On the other hand, if the returns of the security in question are correlated negatively with the returns of the portfolio, its inclusion in the portfolio will reduce the total risk associated with the portfolio. This is fairly intuitive. If a person has shares that are likely to fall in value in the event of a recession (for example, mining stocks), it makes sense to 'hedge' this risk by purchasing shares that will not be affected negatively by a recession—or at least will be less affected (for example, a budget supermarket chain).

The idea can be demonstrated for a portfolio of two securities in the simple equations below (the same procedure can be performed for portfolios with more than two securities, although the math-



ematics becomes much more complicated) (Copeland, Weston and Shastri 2005). The expected portfolio return,  $E(r_p)$ , is the weighted average of the expected returns of each security,  $E(r_i)$  (Equation 1).

$$E(r_p) = X_1 \times E(r_1) + X_2 \times E(r_2) \quad (1)$$

In Equation 1,  $X_1$  and  $X_2$  are the proportions of the portfolio made up of security 1 and security 2, and  $E(r_1)$  and  $E(r_2)$  are the expected (mean) returns of security 1 and security 2. Portfolio risk,  $\sigma_p$ , is based in part on the weighted average of the risk of each individual security, but is determined also by the correlation between the two securities (Equation 2).

$$\sigma_p = \sqrt{X_1^2 \sigma_1^2 + X_2^2 \sigma_2^2 + 2X_1 X_2 \rho_{12} \sigma_1 \sigma_2} \quad (2)$$

In Equation 2,  $\rho_{12}$  is the correlation coefficient between the two return streams and  $\sigma_1$  and  $\sigma_2$  are the standard deviations of returns to security 1 and security 2. Because there is a correlation component in the calculation of a portfolio's risk but not in the calculation of its return, including a 'low-return, low-risk' security in the portfolio can often reduce the total portfolio risk considerably with only a small decline in its expected return. This reasoning is not quite so intuitive. In this way, MVP can be used to identify an 'efficient' set of portfolios, which will minimise risk for any given return, and conversely will maximise returns for a given level of risk.

### The electricity grid in Fiji—applying the mean-variance portfolio

MVP can be applied to the electricity sector in much the same way as it is to financial securities, in order to assess the impact of generation technologies on an electricity grid's risk and expected generation costs. In doing so, it can be used to identify efficient 'portfolios' of generation equipment that minimise risk for any given level of cost, and conversely minimise cost for any given level of risk. The type of risk that is incorporated in this type of analysis is financial risk—that is, the risk that real generation costs will differ from expected generation costs. MVP therefore provides a good measure of energy security in a context where markets are developed and the key threats to security of electricity supply are related to the price of electricity, provided this is determined in the long run by generation costs. This is currently the situation for the electricity grid in Fiji.

MVP was first applied to the electricity sector by Bar-Lev and Katz (1976), who used it to measure the benefits for utilities of diversifying their fuel suppliers. More recently, Shimon Awerbuch (2000, 2006) has applied it to the valuation of electricity-generation technologies (Awerbuch and Berger 2003; Awerbuch, Jansen and Beurskens 2008; Awerbuch and Sauter 2006; Awerbuch and Yang 2008). Awerbuch (2000, 2006) is critical of existing 'engineering-economic' methods used to value investment in electricity-generation infrastructure, based primarily on the least-cost economic analysis of generation equipment performed on a stand-alone basis. He argues that these methods are biased against renewables, as they do not account for their unique energy security benefits (or for their environmental or social benefits) (Awerbuch and Sauter 2006).<sup>4</sup> Instead, Awerbuch proposes using MVP to value investment in generation



technologies, on the basis that these incorporate

- a measure of risk, which is essential when considering investments that are more than 20 years in duration (such as in the electricity sector)
- the cost and risk implications of an investment on the entire portfolio of generation equipment.

Awerbuch uses MVP to identify efficient portfolios of generation technologies in several economies, including the United States, Scotland and the European Union (Awerbuch and Berger 2003; Awerbuch, Jansen and Beurskens 2008; Awerbuch and Yang 2008). MVP has since been used in other settings and is being used increasingly to measure the energy security implications of different generation portfolios (Bazilian and Roques 2008; IEA 2007). The focus of these studies is generally on measuring the energy security implications of renewable technologies. MVP has also been extended in several ways in order to better approximate a complex world (Bazilian and Roques 2008 provide a comprehensive overview). Notable contributions include applying MVP to liberalised electricity markets where electricity suppliers do not share the same return and risk concerns as the grid (Roques, Newbery and Nuttall 2008), and the incorporation of load factors into MVP analysis in order to better value technologies based on whether they provide base, medium or peak-load power (Gotham, Muthuraman, Rardin and Ruangpattana 2009).

In applying MVP to the electricity grid in Fiji, the expected future generation costs of each technology need to be estimated and data on their past generation costs collected. Costs therefore replace returns as the primary indicator of interest when adapting MVP to the electricity sector. Historical data are used to identify the variance of generation costs for each technology

and to correlate these with those of the generation portfolio. Where the cost streams of a technology have a high correlation with those of the generation portfolio, they will not improve energy security, as they will move with the generation costs of the grid. This would be the case for gas in Fiji, as gas prices are highly correlated with those of oil, which largely determines variations in the cost of diesel generation in Fiji. Incorporating gas into Fiji's electricity grid would therefore make Fiji more vulnerable to international fluctuations in the price of fossil fuels. On the other hand, the cost streams of most renewable technologies (excluding bio-fuels) are not correlated with those of diesel generation. This is because the most significant cost associated with diesel generation is diesel fuel, whereas that of renewables is the capital cost of the technology, not influenced in a significant way by fluctuations in the price of diesel. As such, renewables can be expected to improve the security of electricity supply in the Fijian grid. A thorough MVP analysis can identify the extent to which they are expected to do so and which portfolio of technologies will provide the lowest level of risk for a given cost.

To go back to the simple example outlined above, consider an electricity grid with a high-risk but lower-cost technology 1 (the equivalent of diesel generation in Fiji when oil prices were low) and a low-risk but higher-cost technology 2 (the equivalent of wind power). The expected portfolio cost,  $E(c_p)$ , is the weighted average of the expected cost of each generation technology,  $E(c_i)$  (Equation 3).

$$E(c_p) = X_1 \times E(c_1) + X_2 \times E(c_2) \quad (3)$$



In Equation 3,  $X_1$  and  $X_2$  are the proportions of the total generation equipment made up of technology 1 and technology 2, and  $E(c_1)$  and  $E(c_2)$  are the expected (mean) generation cost of technologies 1 and 2. The risk of the generation portfolio,  $\sigma_p$ , is based in part on the weighted average of the risk associated with the cost streams of each individual technology, but is determined also by the correlation coefficient between the costs of the two technologies (Equation 4).

$$\sigma_p = \sqrt{X_1^2 \sigma_1^2 + X_2^2 \sigma_2^2 + 2X_1 X_2 \rho_{12} \sigma_1 \sigma_2} \quad (4)$$

In Equation 4,  $\rho_{12}$  is the correlation coefficient between the two cost streams, and  $\sigma_1$  and  $\sigma_2$  are the standard deviations of costs of securities 1 and 2, respectively. Once again, provided that any proportion of technologies 1 and 2 is permitted in the electricity grid, MVP can be used to identify 'efficient' portfolios of technologies 1 and 2, which for any given cost level minimise risk, and for any given risk level minimise cost. This set of 'efficient' portfolios is illustrated in Figure 3.

Figure 3 demonstrates the portfolio effect of changes in proportions of technologies 1 and 2 on the costs of generation and the risk associated with those costs changing. Because the cost streams of technology 1 and 2 are not perfectly correlated, investing in a portfolio that uses both technologies will reduce the total risk of the portfolio. A utility should aim to have the lowest possible generation costs for any given level of risk and the lowest possible level of risk for any given cost. Where exactly it wishes to be on the efficiency frontier will depend on its aversion to risk. If it is more risk averse, it will want a portfolio similar to that at point C. If it is not risk averse and

wants only to lower costs, it will want a portfolio like that at point A (comprising only the risky technology 1). The utility will not want a portfolio between C and E, as at any point on this line both risk and costs are higher. Portfolio B is therefore superior to portfolio E: it has the same level of risk but a much lower cost. A similar figure can be constructed for a portfolio with more than two technologies. In this more complex (and realistic) scenario, the utility could have a portfolio that lies below the efficiency frontier—say, where risk is similar to that at point B but cost is greater, as is in fact likely to occur in the real world.<sup>5</sup> MVP can therefore provide guidance on possible investments in generation technologies that might lower portfolio generation costs with no effect on portfolio risk (or vice versa).

There are, however, several complicating factors that need to be incorporated into the MVP analysis in order for it to better reflect the real world. First, the load factors of different technologies need to be considered. Standard MVP does not account for the ability of various technologies to meet varying loads of power. For example, photovoltaic solar panels can provide power at night only by using expensive battery-based energy storage; however, demand for electricity is often at its peak in the early evening. Diesel generation on the other hand is suited for production of 'peak power', as it can be simply 'switched on'. An MVP analysis needs to ensure that there is sufficient generation capacity that can be 'switched on' to meet demand when needed (Gotham, Muthuraman, Rardin and Ruangpattana 2009 develop a method for incorporating load factors in an MVP analysis). A second point is related to the first. Some renewable technologies are intermittent by nature—namely, solar and wind power. They can meet only a certain percentage of the total electricity supply without investment in costly 'backup' generation capacity that

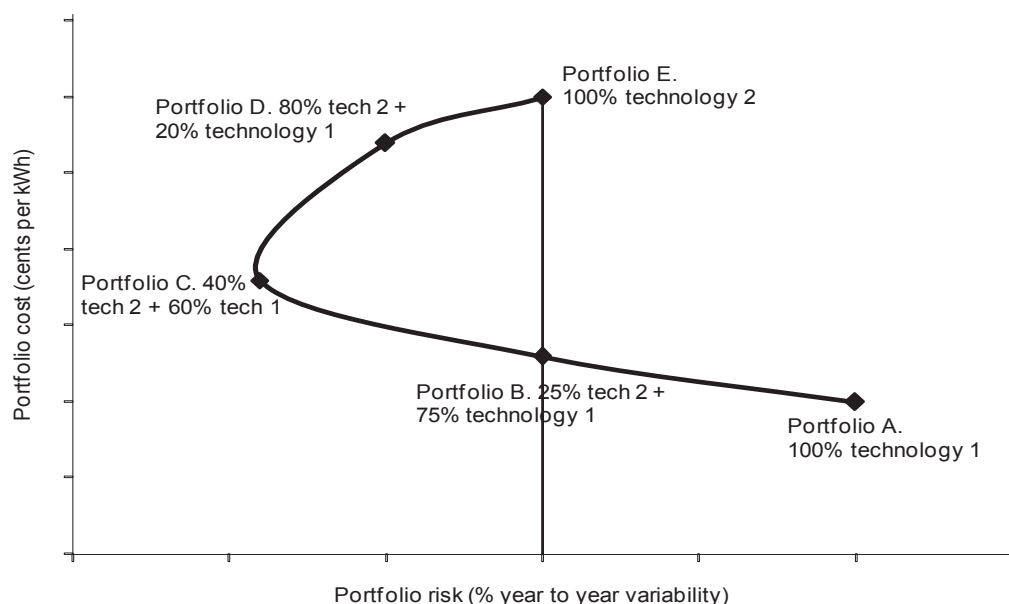


would provide electricity in the event that these renewables stopped providing electricity (Diesendorf 2007; Eaves and Eaves 2007; Gotham, Muthuraman, Rardin and Ruangpattana 2009; IEA 2007; Ölz, Sims and Kirchner 2007). Limits therefore have to be placed on the amount of these technologies 'allowed' in the MVP analysis. Finally, a fairly obvious point is that there are limits to the availability of some forms of energy—for example, in Fiji, there might be limits to the availability of high-wind areas suitable for economically viable, wind-based generation. These limits need to be incorporated into the MVP analysis. Going back to the example provided above, this might mean that technology 2 can provide a maximum of only 25 per cent of the grid's total electricity—although the exact figure will be determined by the composition of

the rest of the generation technologies used in the grid. Portfolios left of portfolio B are therefore not possible without costly backup generation capacity.

Most important in the case of Fiji is the risk of drought affecting generation from hydropower. This is related to the point above: limits must be placed on the amount of hydropower that is allowed to supply the grid without backup capacity. Incorporating this risk in MVP analysis is not, however, straightforward. The risk posed by drought is determined by a range of factors, including capacity margin in the grid (the amount of spare capacity the grid has when demand is at its peak), the storage capacity of hydro sites (and whether these overflow), the location of hydro sites and whether these are in different catchment areas (and the correlation of rainfall patterns

Figure 3 Portfolio effect for two-technology portfolio







in these catchments) and the seasonal nature of rainfall. Different utilities will also have different views on what is an acceptable level of risk.

Estimates of rainfall probabilities are also uncertain, based as they are on historical rainfall data. Future changes in climate resulting from greenhouse gas emissions are likely to change rainfall patterns; however, it is impossible to predict accurately the nature of these changes. The general consensus on future climate change in lower latitudes is that seasonal variation in rainfall will become more pronounced, with more rainfall concentrated in a shorter 'wet' season. This is also predicted for Fiji; however, the Intergovernmental Panel on Climate Change (IPCC) notes that the range of projections is still large, and whether total rainfall will increase or decrease is uncertain (Parry, Canziani, Palutikof, van der Linden and Hanson 2007). Rainfall in the southern Pacific is predicted for the period 2040–69 to be anywhere between –14 per cent and +14.6 per cent of that in the period 1961–90 (Bates, Kundzewicz, Wu and Palutikof 2008). The exact impact of such changes on hydro generation in Fiji is unclear. More rainfall could boost generation; however, if it occurs only in the wet season, the impact will depend on the storage capacity of hydro schemes (currently fairly low). Furthermore, higher temperatures could lead to greater evaporation of stored water. Clearly, including such analysis in an MVP analysis is difficult without making strong assumptions. It is, however, important to consider such issues when assessing the energy security impact of hydro schemes with lives of more than 50 years.

## **Off-grid electricity in Fiji: measuring cost and risk in rural electrification**

Assessing energy security of off-grid electricity supply in Fiji is less amenable to MVP analysis than grid-connected supply due to both significance of physical supply and the price aspects of energy security. Any method of quantifying the energy security implications of different off-grid technologies is bound to be general in nature and might not adequately reflect the energy security concerns of particular rural communities. The results of any quantitative energy security assessment of off-grid electricity supply in Fiji therefore need to be interpreted with care. This stresses the importance of combining quantitative analysis of energy security with qualitative methods that are better equipped to deal with the great variety of Fijian rural communities. Qualitative discussion should be included in any assessment of energy security, whether focused on grid-connected or off-grid areas. It is, however, especially important in rural areas with off-grid electricity supply.

Attempting to measure the security of off-grid electricity supplies in rural areas can be of value in identifying the principal threats posed to energy security in each setting when complemented by qualitative discussion. Quantitative methods such as the MVP framework cannot tell the whole story, but they can provide a useful way in which to frame qualitative discussion of energy security. They can also be used to assess the relative risk implications of different technologies across similar rural communities. Because physical supply aspects of energy security are significant in off-grid systems, a price-based measure of risk such as that used for the electricity grid does not suffice. Instead, a measure that incorporates physical supply and price





aspects of energy (in)security is needed. The only 'common' measure of overall energy (in)security is the number of hours that electricity is unavailable in an off-grid system. An obvious source of such information would be through surveys or short interviews. For example, residents of a village or settlement might be asked for information on how many hours or days electricity was not available in a given month or year, and the cause (and length) of each outage. These causes might include technical problems or irregular shipping resulting in a shortage of diesel. In order to include the price aspect of energy security, rural electricity users relying on diesel systems (whether households or villages) would also be asked if the price of diesel made it unaffordable and resulted in their not being able to generate electricity. This is only a partial measure of the welfare effects of high diesel prices, as it does not incorporate situations where rural users in fact paid for the more expensive diesel. That element could be included in the 'cost' component by adjusting generation costs accordingly. Any such analysis will, however, be inevitably highly subjective.

The results of the surveys could then be tallied in order to give an indication of the relative importance of each threat to energy security in that particular rural area. This analysis would be valid only for the technology involved in the case study, but it could be compared with rural areas in similar situations that use a different off-grid generation technology. In this way, possible but as yet unused energy sources could be included in the analysis. To give an example, in a hypothetical study of diesel-based electricity generation in a remote village, it might be found that high diesel prices meant that electricity was not available for 31 days in a certain year. In the same case study, irregular shipment of diesel might have resulted in a lack of electricity for 20 days in the given year, while technical problems might have

resulted in electricity not being available for 24 days in that year. This basic tally provides information about what the key threats to energy security in a diesel-based electricity generation system are for a particular village. The information can then be compared with a tally for a similar village that generates electricity using another technology such as solar photovoltaic. To the extent that these villages are similar (sharing geographical, transport and even institutional features), conclusions can be drawn about the energy security implications of each technology for that 'type' of remote community.

The approach outlined above is not an exact or reliable method for measuring energy security on its own. The partial nature of measuring the price aspects of energy security has already been mentioned. Another problem with the approach is that it is not very reliable, based as it is on surveys and/or interviews. The results and some of the terminology are also difficult to define. For example, a statement such as 'the price of diesel made it unaffordable' is not equivalent to a measure of price variability. It could instead relate to the lack of cash income in rural areas. Finally, the analysis will vary between regions and general conclusions about the energy security implications of each technology cannot be made as they can for the electricity grid. Although this makes the analysis more complex, it reflects the reality of energy security in rural Fijian households that depend on an off-grid electricity supply. Threats to energy security are specific to rural areas, which vary greatly in their geography, transport situation and cash income. Cultural issues also play a role in different contexts, influencing what institutional structures for fee collection and/or maintenance will be successful, preferences in the community (through their impact on discount rates and risk aversion) and use of land on which the electricity system is based. In Fiji, these differences are expected



to be most pronounced when comparing indigenous Fijian villages with Indo-Fijian settlements.<sup>6</sup>

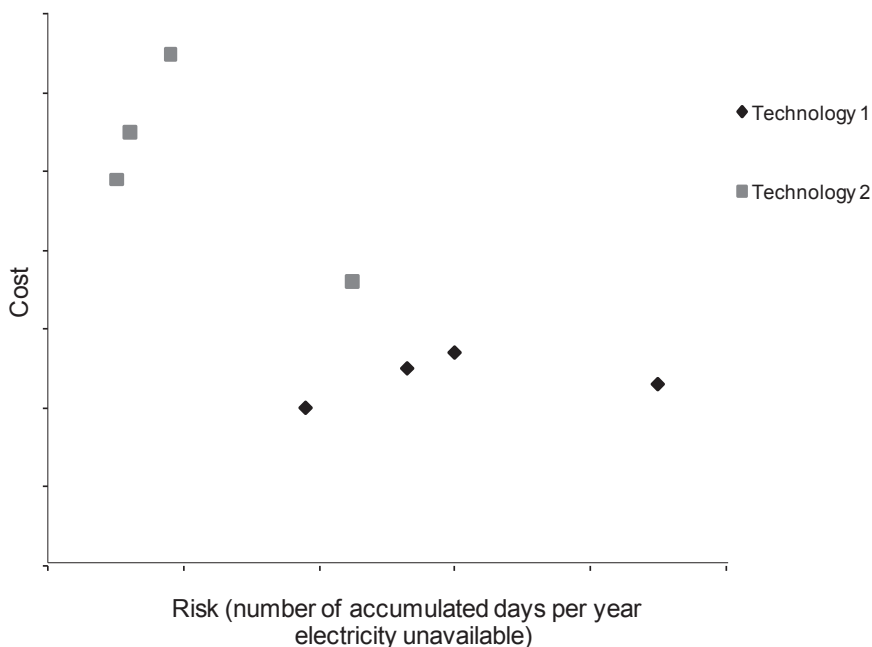
The analysis can nevertheless be used to compare the suitability of technologies with certain types of rural areas. For example, across small villages in outer islands there might be some consistency in the results. The aggregate risk of a technology can thereby be compared on the basis of the accumulated days (including hours) in which electricity was unavailable across different villages. These can be considered together with the cost of the technologies in a price-risk matrix such as the example shown in Figure 4, which would involve surveys of eight electrified outer island communities (in this hypothetical example, four are electrified with diesel generation and four with solar photovoltaic).

Such an analysis is useful where data are collected from several rural communities. It must, however, be accompanied by qualitative discussion of what threats produced the results and what features of each rural community made it susceptible to particular energy security risks.

## Conclusion

Energy security arguments are being used increasingly in Fiji and other Pacific island countries in favour of renewable-based electricity generation. The vulnerability of Pacific island economies to oil-price volatility in the past few years and its effect on the security of supply in grid-connected and off-grid areas add weight to these arguments. Despite this, there have been few

Figure 4 **Hypothetical example of a technology comparison for electrified outer island communities**





explanations of what exactly is meant by the term 'energy security' in Pacific island countries and no published attempts to assess the impact of renewable technologies on that security comprehensively. Quantitative evaluation of the contribution of renewables to energy security is important if their benefits to Fiji and other Pacific island countries are to be adequately assessed.

This article has provided a definition of energy security that goes beyond the strategic concerns of long-term physical supply shortages that dominate historical understandings of the term. Instead, it has argued that energy security can be understood in terms of economic welfare, reflecting the extensive international markets that exist for modern forms of energy. In Fiji (and other Pacific island countries), however, the lack of well-functioning markets, especially in rural areas, also needs to be considered. Therefore, this article describes energy security in Fiji as consisting of price and physical supply aspects, with the relative importance of each aspect depending on the level of development of markets for energy.

Two methods are proposed for measuring the security of electricity supply in grid-connected and off-grid areas and for evaluating the impact of technologies. These methods could easily be adapted for use in other Pacific island countries (or small island developing states) that face similar energy security issues in their electricity sectors. For the grid, the mean-variance portfolio (MVP) approach is suggested as a useful method for assessing the price aspect of energy security for different generation technologies. Technologies are valued in MVP theory based on their expected future cost and the historical variance of their costs, which is used as a measure of risk. Furthermore, it is the effect of a technology on the cost and risk of the portfolio (or generation mix) that matters for the electricity grid. There are a number of complicating

factors that should be included in an MVP analysis for it to reflect the real world better. This article briefly discussed several of these and suggested ways in which they could be incorporated.

Off-grid electricity supply in rural Fiji is not amenable to MVP analysis. Quantitative methods can, however, provide a useful framework for qualitative discussion of energy security issues. This article describes an alternative method to MVP that can be used to quantify risk for off-grid systems. This method is useful in comparing technologies across similar types of communities and in identifying the relative importance of threats to the security of electricity supply in such areas. Its results, however, are not as clear or as comprehensive as those of the MVP analysis proposed for the Fijian grid—and therefore should not be used in isolation.

The two methods outlined in this article provide a useful way of assessing the energy security implications of electricity-generation technologies in Fiji that might also be useful in other small island developing states. In Fiji, there are currently several electricity-related investment projects under way or under consideration. Many of these are renewable energy projects. Assessing the energy security impact of these investments in a systematic way will help to ensure that: 1) energy security issues are adequately considered when investment decisions are made; and 2) the public utility (the FEA) and policymakers are fully informed of the benefits and costs of competing infrastructure investment options. In rural Fiji, quantitative evaluation of energy security provides a useful way of framing and guiding broader discussions about threats to the security of electricity supply in rural areas dependent on off-grid generation, and ways in which those threats can be addressed. If used in the planning stages of rural electrification programs, this type of analysis could help



improve the reliability and performance of rural electricity systems installed as part of those programs.

## Notes

- <sup>1</sup> Whether this situation continues will depend on the decisions of Fiji's political leaders. Cabinet postponement of the implementation of a fuel price surcharge recommended by the Commerce Commission in 2008 has already shown the potential for tariffs to be kept below FEA costs on the basis of social and political reasons (FEA 2007).
- <sup>2</sup> These conclusions stem from analysis of failed renewable energy programs implemented in the Pacific islands during the 1980s and early 1990s. These programs were found to have not sufficiently considered the 'soft' aspects of energy systems, such as establishing institutional arrangements to ensure that equipment was maintained, repaired and operated appropriately; that training was provided to technicians in remote communities; and that fees were collected in order to purchase parts for equipment when necessary. See Bygrave (1998) for a detailed analysis.
- <sup>3</sup> As mentioned previously, government policies and regulations that subsidise electricity provision clearly also impact on prices charged to the consumer. This topic alone is worthy of an article and cannot be discussed in any depth here. Suffice to say that in the long run, subsidies must be financially sustainable, meaning that electricity prices cannot remain too far below the generation costs without adversely affecting the government budget. In Fiji, although the FEA is a corporatised entity that seeks to make a profit, the Fijian government ultimately sets electricity prices. This involves cross-subsidies between consumers in urban centres such as Suva, who effectively pay for the below-cost tariffs charged to rural grid-connected users in Viti Luvu, and consumers in Ovalau and Vanua Levu. Both types of consumers pay the same electricity tariffs

(once infrastructure is developed to extend the grid to rural areas), despite the costs of electricity provision being different. The FEA (2008) estimates that in 2008 it incurred costs of F\$22 million in supplying electricity to these 'non commercial obligation' areas.

- <sup>4</sup> Incidentally, he also argued that hedging did not offer a means of dealing with long-term energy security risk posed by oil price volatility due to the low liquidity of energy-sector hedging markets after one year (Awerbuch, 2000).
- <sup>5</sup> Awerbuch (2006) shows that in the European Union, Mexico and the United States, generation portfolios are below the efficiency frontier, with Mexico the country furthest from the frontier. He posits that developing countries generally tend to be further from the efficiency frontier than industrialised countries, although he does not provide reasons for this.
- <sup>6</sup> Costs often also differ between these communities due to the different spatial organisation of communities, with indigenous Fijian villages generally more concentrated than Indo-Fijian settlements, resulting in lower wiring costs for community-based diesel generation.

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